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NEUTRON–ANTINEUTRON OSCILLATIONS AT THE SURFACE OF NUCLEI[1]

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Abstract

We discuss some aspects of possible neutron–antineutron oscillations in nuclei. The phenomenon occurs mostly at the surface of nuclei, and hence *i)* is not very sensitive to medium corrections and *ii)* makes use of the antinucleon-nucleus interaction in a region probed by experiments at CERN.

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The relevance of neutron–antineutron oscillations for testing physics beyond the standard model was stressed in several contributions at this Workshop, in particular by Mohapatra [1]. The question now is how to detect neutron–antineutron oscillations, or how to set an upper limit on their rate. We refer to Alberico's talk for a comprehensive survey [2]. In the present contribution, we wish to stress some properties of the potential-model approach, which in our opinion make it rather reliable.

Consider for instance an S-wave neutron in deuterium. It is governed by a radial Schrödinger equation

$$u''(r) + m\,[E - V_n(r)]\,u(r) = 0, \tag{1}$$

where notations are obvious. With a $n \leftrightarrow \bar{n}$ transition potential ϵ, the wave function gets an antineutron component $\bar{u}(r)$ which to leading order is given by the inhomogeneous equation

$$\bar{u}''(r) + m\,[E - V_{\bar{n}}(r)]\,\bar{u}(r) = m\epsilon u(r), \tag{2}$$

where E and u are now frozen. This leads to an estimate of the decay width of deuterium in terms of the annihilation part of the antineutron potential

$$-\frac{\Gamma}{2} = -\frac{1}{2T} = \int_0^\infty \bar{u}^2(r)\mathrm{Im}V_{\bar{n}}(r)\mathrm{d}r. \tag{3}$$

It is rather straightforward to generalise these equations to larger nuclei, once each neutron is described by its appropriate shell-model wave-function.

Such a set of equations gives results which are stable with respect to variations of the basic ingredients, as stressed, e.g., by Ericson and Rosa-Clot [3] in a different context. Moreover, this formalism provides the relative contribution of each neutron shell, and within a shell, the weight of the various parts in the integration over the distance r.

This analysis was carried out in Ref. [4], and its results were confirmed in further investigations [5]: neutron–antineutron oscillations, if any, occur mostly in outer shells, and near the surface of the nucleus. In particular:

- nuclei with weakly-bound neutrons offer more favourable rates. As discussed during the oral presentation, heavy water would be slightly better than ordinary water, because of the loosely-attached neutron in deuterium.
- the antineutron wave function is peaked outside the nuclear density.

These properties survive changes in the assumed shape of the neutron potential, and can be explicitly seen in toy models such as square-well or separable potentials, for which calculations can be performed analytically.

This peripheral character of nuclear instability can be explained as follows. In nuclear medium, a neutron which considers the possibility of oscillating is immediately refrained to do so when it feels the large gap between the average potentials V_n and $V_{\bar{n}}$. Far away, this gap vanishes, for both potentials go to zero. On the other hand, one would not care too much about an antineutron at large distance from the centre, as it has no nucleon to interact with. The best compromise takes place at the surface,

where the neutron is free enough to oscillate, and the medium is still dense enough to annihilate freshly-produced antineutrons.

The peripheral character of neutron oscillations in nuclei has two important consequences:

• Contrary to the neutron potential V_n (and its by-product $u(r)$, the neutron wave function) which is well constrained by decades of phenomenological studies, the antineutron potential $V_{\bar{n}}(r)$ is not well known inside the nucleus. However, experiments at the LEAR facility of CERN with antiprotonic atoms, or with antiproton beams scattered on nuclear targets, provide stringent constraints on this interaction near the nuclear surface [6]. This is precisely the domain we need for neutron oscillations.

• Deeply inside a nucleus, the transition operator ϵ could be renormalised, or receive new contribution. This is discussed, e.g., by Kabir [7]. The quasi-free neutrons which contribute to most of the decay of the nucleus experience an ϵ potential which is identical or very close to τ^{-1}, where τ is the oscillation period of free neutrons.

The comparison between free-neutron and bound-neutron experiment has been the subject of intense debates, and one of the authors (J.M.R.) would like to acknowledge discussions on the subject at I.L.L., Grenoble, with the late R. Marshak and W. Mampe. As long as negative results are obtained, bound nuclei provide a rather reliable lower bound on the oscillation period τ. The scaling properties of Eqs(2-3) implies for τ a relation

$$T = T_R \tau^2 \tag{4}$$

to the lifetime T of a given nucleus. When the nuclear factor T_R is computed with the typical medium-size nuclei used in proton-decay experiments, one gets that $T \geq 10^{32}$ y implies $\tau \geq 10^8$ s [8], comparable to the latest result with free neutrons at Grenoble [9]. The perspective of checking directly $\tau \geq 10^{11}$ s in the foreseen experiment at Oak Ridge corresponds to limits on T which are not conceivably reachable in underground experiments.

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